(Ed: (1) now reads: compositional differences were observed in slow (low latitude) solar wind and in fast (high latitude) solar wind.)

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REPORTS

Ulysses Above the Sun's South Pole: An Introduction

Edward J. Smith, Richard G. Marsden, D. Edgar Page

Ulysses has explored the field and particle environment of the polar region. The solar wind speed was fast and nearly constant above --50° latitude. compositional ~~Heavy ions were more~~ differences were observed ~~abundant~~ in slow (low-latitude) solar wind and fast (high-latitude) solar wind, The radial magnetic field did not change with latitude, implying that polar cap magnetic fields are transported toward the equator. The intensity of galactic cosmic rays was nearly independent of latitude. Their access to the polar region Is opposed by outward-traveling, large-amplitude waves In the magnetic field.

The goal of the Ulysses mission was to escape the confines of the solar equator, where all previous measurements had been made, and to reach the vicinity of the sun's poles (1). The spacecraft, launched on 6 October 1990 from the space shuttle, used three upper stages to escape the Earth's gravity en route to Jupiter. The encounter with Jupiter on 11 February 1992 rotated the orbit 80° relative to the solar equator. The resulting flight path (Fig. 1) passed under the south pole of the sun, returned to the ecliptic (March 1995), and will pass over the north pole (June through September 1995). Ulysses reached a maximum latitude of -80.22° on day 256 (13 September) of 1994 (Fig. 2). The radial distance from the sun at that time was 2.29 astronomical units (AU).

Ulysses spins at 5 revolutions per minute about the center line of a high-gain antenna pointed at Earth. The spacecraft contains nine body-mounted hardware experiments (2). Four sensors lie along an equatorial boom. Two long wires in the equator and a third deployed along the. spin axis are radio- and plasma-wave antennas. These experiments ~~(Tables 1 and 2)~~ (Table 1) are providing comprehensive measurements of essentially all of the fields and particles of scientific interest without gaps in energy or frequency coverage.

2(a)

The sun's outer atmosphere (3), which is normally visible only at times of eclipse, consists of two distinct regions: a natrow shell (the chromosphere) lying just above the solar surface (the photosphere) and a more extended highly structured upper atmosphere (the corona). At the high temperatures and low densities in these regions, the solar gas is a completely ionized plasma consisting solely of electrons and the electrically charged atoms (ions) from which they have been removed. A conversion of random thermal motion into directed motion, analogous to that occurring in a rocket engine, causes part of the corona to flow outward as the high-speed solar wind.

The sun, like most planets and other stars, is magnetized. Electrical currents inside the sun produce magnetic fields that extend upward through the surface and into the atmosphere. The magnetic fields impose a large-scale structure on the corona. Near the equator, the magnetic lines of force begin and end in the photosphere to form loops (closed field lines), These field lines are customarily stretched out and appear as visible coronal structures called streamers. At high latitudes, the field lines can have one end on the sun with the other end extending radially outward (open field lines). In these regions, the plasma continuously flows into space, and the lower density that results causes dark regions called coronal holes.

As the sun rotates, the solar wind in the ecliptic alternately comes from low and high magnetic latitudes, and its speed varies from low to high values. Before teaching the orbit of Earth, the high-speed wind overtakes the slower wind and compresses it to form regions of piled-up magnetized plasma (corotating interaction regions). This interaction can lead to the generation of collisionless shocks rtnd the local acceleration of particles to high energies.

The solar wind expands and pushes the nearby interstellar plasma out of the solar system to an estimated distance of about 100 AU to form the heliosphere (4). Interstellar gas is only partially ionized and neutral atoms (mostly hydrogen and helium) can enter the heliosphere directly as can interstellar dust. Galactic cosmic rays, atomic nuclei accelerated to relativistic speeds in distant cataclysmic events, also enter the heliosphere but are strongly affected by the solar wind magnetic fields.

The recent polar pass by Ulysses showed that the solar wind (5) increased in speed from -400 to -750 km/s. Up to a latitude of ~-30° (approximately the tilt angle of the sun's magnetic dipole), large variations in speed were seen at the solar rotation period of -26 days. Above --50° latitude, the solar wind became nearly constant in speed and was coming from a coronal hole covering the south polar cap.

The heavy-ion compositions of the slow (low-latitude) and fast (high-latitude) solar wind were markedly different, with sharp compositional boundaries between the two types of flow (6). Magnesium, which ionizes relatively easily, was more abundant than oxygen in slow streams, but the Mg/O ratio changed abruptly between slow and fast streams. The abundances were not what would be expected for ions formed in the hot corona but are representative of values in the lower temperature chromosphere.

Measurements of the radial component of the magnetic field, which is most easily related to the global solar magnetic field, failed to show a latitudinal gradient (7). Because remote sensing solar measurements reveal a well-developed dipolelike magnetic field, magnetic flux from the poles is being moved toward the equator to yield a uniform field, Models used in the past, which have ignored the effect of magnetic stresses on solar wind acceleration, must be reexamined.

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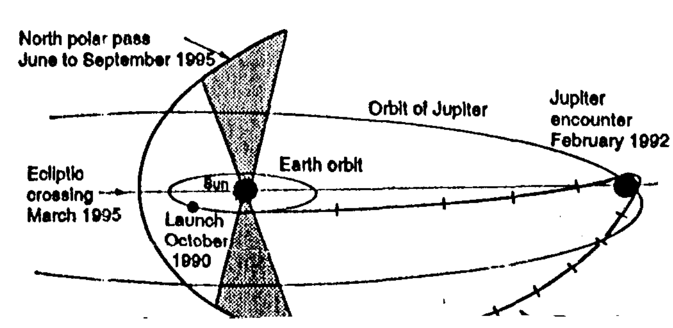

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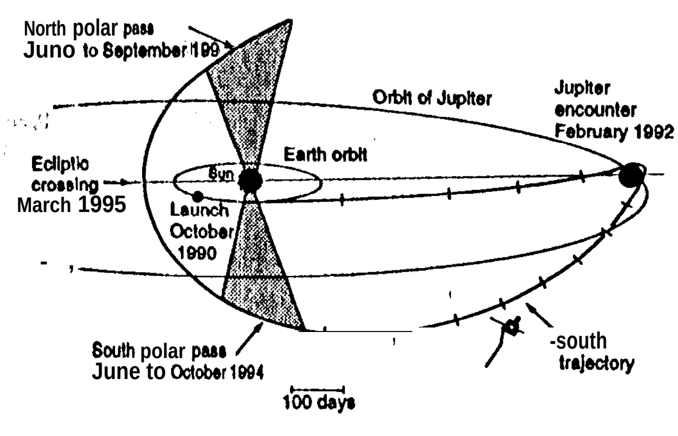

Fig. 1. The flight path of Ulysses from launch to the end of the prime mission. The scientific requirements imposed on the trajectory design were to spend as much time as possible above ±70° latitude and to achieve the highest possible latitude. The spacecraft will continue to follow the highly inclined ellipse for at least the next several hundred years.

E. J. Smith and D. E. Page, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109-8099, USA.
R. G. Marsden, Space Science Department, European Space Agency, European Space Technology Center, Postbus 209, 2200 AG Noordwijk, The Netherlands.

note to editor (2)

(Ed: E stood for Ex-terrestrial-time) physics at one

Ed(3)- for Aeronomy, Physics and Astrophysics and Nuclear physics

Table 1. The nine herdware end two radio experiments on board Ulysses. MPAe, MPE, end MPK are the Max Planck Institutes of xxx, xxx, and xxx; UC is the University of California.

Investigation	Acronym	Principal investigator	Measurement
Magnetic field	VHM/FGM	A. Balogh, Imperial College, London (UK)	Spatial and temporal variations of the heliospheric magnetic field: 0.01 to 44,000 nT
Solar wind plasma	SWOOPS	J. L hillips s Alamos National Laboratory (USA) Ed(4): Phillips	Solar wind Ione: 260 eV to 35 keV per Ionic charge; solar wind electrons: 0.8 to 860 eV
Solar wind Ion Composition	SWICS	J. Geiss, Univ. of Bern (Switzerland), and G. Gloeckler, Univ. of Marylend (USA)	Elemental and Ionic-charge composition, temperature, and mean speed of solar wind ions: 145 km/s (H^+) to 1350 km/s (Fe^{+8})
Radio and plasma waves	URAP	R. G. Stone, NASA Goddard Space Flight Center (USA)	Plasma waves, solar radio bursts, electron density, and electric field (plasma wavea: O to 60 kHz; radio: 1 to 940 kHz; magnetic: 10 to 600 Hz)
Energetic particles and Interstellar neutral gas	EPAC/GAS	E. Keppler, MPAe, Lindau (Germany)	Energetic ion composition: 80 keV to 15 MeV per nucleon; neutral helium atoms
Low-energy Ions and electrons	HISCALE	L J. Lanzerotti, AT&T Bell Labs, New Jersey (USA)	Energetic ions: 60 keV to 5 MeV; energetic electrons: 30 to 300 keV
Cosmic rays and solar particles	COSPIN	J. A. Simpson, Univ. of Chicago (USA)	Cosmic rays end energetic particles ions: 0.3 to 600 MeV par nucleon; electrons: 4 to 2000 MeV
Solar x-rays and cosmic gamma-ray bursts	GRB	K. Hurley, UC Berkeley (USA) and M, Sommer, MPE, Garching (Germany) ✓	Solar flare x-rays end cosmic gamma-ray bursts: 15 to 160 keV
Cosmic dust	DUST	E. Grun, MPK, Heidelberg (Germany)	Dust particles: 10^{-16} to 10^{-7} g
		Radio science	
Coronal sounding	SCE	M. K. Bird, Univ. of Bonn (Germany)	Density, velocity, and turbulence spectra In solar corona and solar wind
Gravitational waves	GWE	B. Bertotti, Univ. of Pavia (Italy)	Doppler shifts in spacecraft radio signal as a result of gravitational waves

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Large-amplitude, long-period magnetic waves were continuously present in the flow from the polar coronal hole (7), The waves cause the field direction to vary continuously. The wave forms are irregular, covering a broad band of wavelengths, and constitute a form of turbulence. Correlations between the magnetic field and solar wind velocity show that they are Alfvén waves propagating outward from the sun. The longest wavelengths are comparable to the radii of gyration of the cosmic rays and are thought to be impeding their entry into the polar region. The origin of the waves and their effect on the solar wind are also recognized as important issues,

These and other results reported In the accompanying articles are causing a revision in many of our preconceived ideas regarding the solar wind and the heliosphere. The observations have been obtained near sunspot minimum, when the sun is in a particularly simple state. It will also be important to compare the present observations with those obtained next summer when Ulysses passes over the sun's north polar regions.

In the intervening interval, Ulysses will pass through perihelion at 1.34 AU and, as the spacecraft approaches the sun, will gain speed. The latit ude gradients in all of the important physical parameters will once again be surveyed, this time over a much shorter time interval, which will help discriminate against time variations that might masquerade as spatial variations,

After the spacecraft reaches + 70° on 29 September 1995, it will once again head out toward the orbit of Jupiter at 5,3 AU. The orbital period of Ulysses is 6.3 yearn, so that on the next revolution around the sun, the spacecraft will pass over the south and north polar regions during the coming solar maximum in 2000 and 2001.

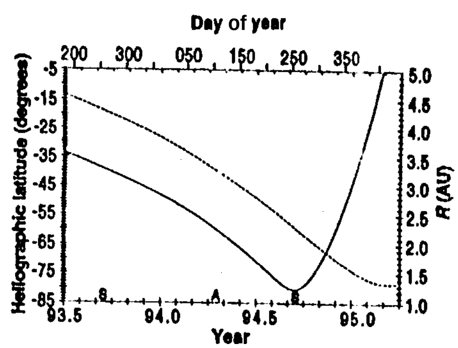

Fig. 2. Radial distance from the sun (dotted line) and heliographic latitude (sold line) of Ulysses while In the polar regions. The radial distance Is given In astronomical units. The maximum heliographic latitude reached was beyond -80°, The polar cap Is defined as the region above -70°, S, September; A, ~~August~~ A pril Ed(5)

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Study	Researcher
Ed(7) Solar wind	

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1. The International Ulysses mission Is a joint undertaking of the American end European space agencies ~~(Table 1)~~. The spacecraft was designed, built, tasted, end is being operated under the direction of the European Space Agency (ESA). The National Aeronautics and Space Administration (NASA) was responsible for the launch and is acquiring the data with the antennas of the Deep Space Net, Scientists In bott Europe and the United States supplied the experi ents and are interpreting the results. The scientific objectives are described In E. J. Smith, D. E. Page, K.-P. Wenzel, *Eos* 72,241 (1991); K.-P. Wenzel, R. Q. Marsden, D. E. Page, E, J. Smith, *Astron. Astrophys. Suppl. Ser.* 92,207 (1992).

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2. The scientific experiments are described In detail in a series of articles In *Astron. Astrophys. Suppl. Ser.* 92, 207-440 (1992).

3. H. Zirin, *Astrophysics of the Sun* (Cambridge Univ. Press, New York, 198S): F'. V. Foukal, *Solar Astrophysics* (Wiley, New York, 1990).

(Ed: E stood ... Extraterrestrial physics at one time)

Phillips

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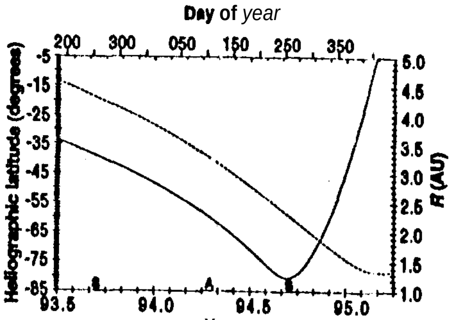

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Ed(7) Solar wind ~~Directional~~ discontinuities	M. Schulz, Lookheed Pelo Alto Research Laboratory (USA)
Mass loss and krn composition	G. Nocl, Univ. of Florence (Italy)
Solar wind outflow	A. Barnes, Ames Research Center (USA)
Comets	J. C. Brandt, Univ. of Colorado (USA)
Ed(8) Shocks and waves	C. P. Sonett, Univ. of Arizona (USA)
Ed(9) Energetic particle transport (or Energetic particles)	J.R. Jokipii, Univ. of Arizona (USA)

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4. ~~D. E. Page, Ed., *Observations of the Outer Heliosphere*, vol. 13 of the *Advances in Space Research Series* (Pergamon, New York, 1993)~~; S. Grzedzielski and D. E. Page, Eds., *Physics of the Outer Heliosphere: Proceedings of the 1st COSPAR Colloquium Held In Warsaw, Poland, 19-22 Sep-*

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tember 1989, vol. 1 of the COSPAR Colloquia Series (Pergamon, New York, 1880).
5. J. L. Phillips et al., Science xxx, xxx (1995).
6. J. Geiss et el., ibid., p. xxx.
7. A. Balogh et al, ibid., p. xxx.
8. J. A. Simpson et al., ibid., p, xxx.
9. This work was supported by the Jet Propulsion Laboratory (JPL), California Institute of Technology, under contract with NASA. E.J.S. is the Ulysses Project Scientist for NASA; D.E.P. is the ESA Science Coordinator in residence at JPL; R.G.M. is the ESA Project Scientist.

1 February 1995; accepted 20 April 1995

(Ed. (12b): If Table 2 has to be referred to in the text rather than in a footnote, I suggest adding a sentence to the end of paragraph #2: Six Interdisciplinary Study teams (Table 2) are assisting in data interpretation.